RECOMMENDATIONS AND IDEAS FOR RESEARCH

In summer of 2004, the Scientific Committee of the International Whaling Commission, comprised of approximately 200 of the world's leading whale biologists, met in Sorrento, Italy, and released its annual yearly review of "the major issues affecting cetacean conservation." The July 19, 2004 report, summarizing most recent scientific findings on the impacts of human noise on cetaceans, cites anthropogenic noise as among the major issues affecting whale and dolphin conservation worldwide.

The committee determined, "There is now compelling evidence implicating anthropogenic sound as a potential threat to marine mammals. This threat is manifested at both regional and ocean-scale levels that could impact populations of animals" (IWC 2004(b)). The Committee went on to note the potential for negative "cumulative or synergistic effects of sounds" with non-acoustic environmental threats such as pollution and loss of habitat (IWC 2004(a)). The Committee concluded:

> *Whilst noting that there is considerably more scientific work needed, the Committee emphasises that measures to protect species and habitats cannot always wait for scientific certainty, as encoded in the precautionary principle. This is especially true for cases involving the exclusion of an endangered population from its habitat. ...As a result, the Committee* ***agrees*** *that noise should remain a standing priority item on its agenda.* [IWC 2004(a), emphasis added.]

Along with this recommendation for a precautionary approach to anthropogenic noise, the Committee identified the importance for resource managers to consider noise within marine protected areas (MPAs) such as CINMS. Specifically, it called for "Inclusion of anthropogenic noise assessments and noise exposure standards within the framework of national and international ocean conservation plans (e.g., consideration during designation of critical habitats, MPAs and ocean zoning)" (IWC 2004(a)), and for the investigation of "novel applications of conservation tools such as designation of... marine protected areas and ocean zoning... as a means to protect cetacean populations from chronic and intense-episodic anthropogenic noise" (IWC 2004(b)).

Within the discussion of anthropogenic noise and the natural resources of CINMS, the IWC call for action could not be more timely or more pertinent. What's more, it should be clear from the data reviewed in the pages of this report that the threats and recommended responses identified by the IWC are applicable to an array of non-cetacean marine wildlife including pinnipeds and fishes. Put simply, anthropogenic noise pollution represents a growing ecological problem that must be addressed globally and locally.

Today CINMS and the National Sanctuary Program have many opportunities for useful research, monitoring and management of noise pollution and its known and potential impacts on marine resources. By moving to address anthropogenic noise and realize these opportunities, Sanctuary management will make a significant step forward in its mission to conserve CINMS and the natural resources harbored within it. Addressing and engaging the issue of noise pollution could benefit CINMS resource management and stakeholders, as well as contribute needed leadership and momentum in establishing the regional, national and intra-governmental partnerships that will be crucial in addressing marine noise pollution effectively.

Toward that end, two sets of specific recommendations for initiatives and research areas are outlined below.

The first set of recommendations, "Sources and Impacts," targets the lack of quantitative physical and ecological data on noise and its impacts on CINMS resources. Fulfillment of these recommendations would provide fundamental data to illuminate patterns of noise emissions and related biological impacts, and thus inform future management of Sanctuary resources.

Sources and Impacts

1. *Initiate Sanctuary-wide noise monitoring.* An ongoing hydrophonic monitoring program should be initiated as soon as possible to gauge ambient sound levels within CINMS, identify what sound sources are significant and at what levels they occur in the Sanctuary, and track changes in these values over time. Such monitoring would provide insight into the human activities in and around the Sanctuary, while long term data on ambient sound levels and temporally discrete acoustic events would assist in investigations of the behavior, abundance and survival of various biological communities.

2. *Study hearing capabilities of Sanctuary wildlife.* Further study of received sound-level impact thresholds (e.g. frequency, amplitude and exposure durations that induce behavioral response, physical trauma, cumulative impact, etc.) for individual species resident in the Sanctuary would assist Sanctuary management, at least for conservation of endangered or acoustically sensitive species. More data on the sensitivity of marine reptiles and invertebrates to anthropogenic noise would help fill significant gaps in bioacoustics literature, as well as round out understanding and management of noise pollution impacts on CINMS resources.

3. *Study anthropogenic noise impacts on Sanctuary ecology.* Investigators should examine effects from particular noise sources on specific biological communities. As the primary noise producing activity with the highest potential for impact to Sanctuary ecology, scientific investigation of large vessel traffic sound should be aggressively undertaken. Direct research on shipping noise impacts on Sanctuary fish species, including impacts to reproduction, recruitment and foraging, would both enlighten Sanctuary and fisheries management, and shed light on a little studied area in fisheries ecology. Similarly, any research on shipping noise and marine invertebrates would be extremely useful in estimating whether such species are

subject to significant impacts from ensonification of their habitat from large vessel traffic noise.

4. *Research indirect anthropogenic noise impacts to Sanctuary ecology.* Establishment of an appropriate stringency of regulation for noise emissions (commensurate with the noise "budget" of the Sanctuary ecosystem) requires a more detailed understanding of the secondary ecological impacts of noise pollution. For example, what are the ecological consequences within the Sanctuary of hypothetical cetacean avoidance of heavily ensonified waters near the shipping lanes? Does an elevated ambient noise level reduce recruitment of any Sanctuary fish species, and if so, what are the impacts on predators of those fishes? Answers to such questions could eventually provide Sanctuary managers with data to craft more holistic, effective regulation.

The second set of recommendations, "Policy and Partnerships," aims to identify and build potential for specific initiatives to reduce the impact of noise in the Sanctuary. In order to enact the precautionary management of noise pollution in CINMS advocated in this report, further data on the major noise-producing activities must be compiled, and research on the existing policy frameworks that regulate those activities must also be initiated. Gathered information will inform and empower Sanctuary resource managers to appropriately address Sanctuary noise pollution.

Policy and Partnerships

1. *Establishment of a vessel traffic-monitoring program to log and quantify vessel traffic through the Sanctuary.* The non-governmental Southern California Marine Exchange is the only organization known to systematically maintain large vessel traffic data related to Southern California, and its database captures Santa Barbara Channel traffic inefficiently and indirectly. This information should be gathered in CINMS directly. Such data would be highly useful for understanding other impacts to the Sanctuary from large vessel traffic as well as noise, such as airborne diesel exhaust emissions and chemical water pollution.

2. *Develop partnerships.* Establishing CINMS as a partner in regional and national noise pollution monitoring, research and management partnerships will be critical. Obvious examples of collaborative partners include west coast National Marine Sanctuaries, the University of California, and state and federal agencies, such as NOAA Fisheries, the Marine Mammal Commission, US Fish and Wildlife Service, and the US Coast Guard. The CINMS should explore opportunities for collaboration with the US Navy as a means to (a) access historical acoustical data, (b) encourage the distribution of ship quieting and other technologies, and (c) better inform the Sanctuary of future naval activities. Another example would be for NOAA's National Ocean Service to coordinate with University of California researchers to locate and monitor hydrophones for acoustics research in CINMS and California's other three National Marine Sanctuaries.

3. *Engage the shipping industry.* Fostering collaboration between CINMS and the shipping companies and consortiums whose fleets or member companies regularly pass through the Sanctuary will benefit all. Initiating dialog with shippers and shipping organizations could result in noise reduction in the Santa Barbara Channel as well as provide valuable information for shippers interested in reducing noise emissions for vessel efficiency or conservation of particularly sensitive marine areas.

4. *Research international policy and regulation.* Addressing noise pollution in CINMS may require securing international cooperation, and thus working through international policy frameworks such as MARPOL (International Convention for the Prevention of Pollution from Ships 1973/1978), and the International Maritime Organization. CINMS resource managers would greatly benefit from an assessment of the costs, benefits and feasibility of regulatory options available within these international frameworks, such as modification of the Southern California Vessel Traffic Separation Scheme (VTSS) to reroute some or all large merchant vessels currently passing through the Sanctuary, and establishment of CINMS as an internationally recognized marine protected area.

5. *Create a role for the Research Activities Panel (RAP).* The RAP for the Sanctuary Advisory Council (SAC) should review and report to the SAC on any scientific, commercial or non-classified military activities with significant acoustic emissions proposed to be conducted within range of influencing CINMS ecology. As discussed above, activities well outside the boundaries of the Sanctuary may produce noise that could impact CINMS resources. Sanctuary managers and stakeholders should be made aware of such activities, and avail themselves of the RAP's professional assessment of potential impacts.

Obviously such policy and partnership research will be most fruitful if conducted in conjunction with scientific research, so that quantitative data on noise impacts in the Sanctuary become available for the establishment of meaningful goals for future collaborative or regulatory initiatives.

Policy research could also be useful in enhancing the Sanctuary's role in the permitting process for the more temporally discrete noise production from peace-time military low and mid-frequency active sonar exercises, as well as commercial and scientific seismic surveying conducted in an influential proximity to the Sanctuary. For example, in 1999, the collaborative, stakeholder initiative resulting in the "High Energy Seismic Survey Review Process and Interim Operation Guidelines for Marine Surveys Offshore Southern California" delineated the review process and impact mitigation protocol for oil and gas seismic surveys (HESS 1999). However, the guidelines were intended to be interim pending additional research on the potential impacts of such activities. The HESS guidelines should be reviewed and updated with increased CINMS involvement, and include investigation of how such guidelines should be applied to other major noise-producing activities such as military and scientific projects.

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APPENDIX A

BASICS OF ACOUSTICS SCIENCE [adapted from Roussell (2002) and WDCS (2003)]

For sound in a given medium (such as air or water), the *amplitude* of the soundwave is attributed to the amount of energy of the wave, or its wave height, and is associated with perceived loudness. Amplitude is called *intensity* when related to the density of the media through which the sound is traveling. Frequency is the distance between sound wave peaks, or the "rapidity" of the given wave, and is measured in cycles per second or Hertz (Hz). In other words, the intensity and the frequency of the soundwave make the molecules of the media move more or less far away from their original location and vibrate more or less fast respectively, and therefore are the two principal components used as descriptors of the nature of sound. For reference, the approximate range of human hearing stretches between 20-20,000 Hz (or 20 kHz). Sounds with frequencies below 20 Hz are called **infrasonic** and those above 20,000 are called **ultrasonic**. Ultrasonic waves are often used in human and animal sonars, and in medicine, to measure sizes and distances to obstacles. Dogs in general can hear as high as 45 khz, while cats and bats can hears frequencies as high as 75 -100 khz.

Ideally, acousticians would be able to measure intensity (what humans perceive as loudness) directly, but practically it is easier to measure and detect changes in pressure and then convert these to intensities. However, the use of pressure as a measurement unit presents the acoustician with two problems. The first is related to the range of pressure differences that the human auditory system can detect (10 – 100,000,000 *micro-pascals*, or μPa) and the second is related to the way in which the human auditory system processes differences in pressure, i.e. how it judges relative loudness. The former is a practical problem where the magnitude of pressure differences detectable by the human ear can make calculations clumsy, and the latter is a subjective problem whereby the human auditory system processes pressure differences logarithmically, and judges these relatively. For these reasons the **Decibel Scale** and the dimensionless unit the **Decibel** were introduced: sound intensity is measured in decibels (dB), which is a *logarithmic* scale comparing the intensity of the sound measured to that of a reference sound.

Logarithmic measurement is based on change in orders of magnitude (like the Richter Scale) rather than in individual units, which helps in the case of measuring and calculating sound intensity because of the enormous range of pressure variation (which our ears interpret as sound) that the human ear can detect. Thus, an increase of 3 dB is approximately a doubling of intensity, while an increase of 10 dB is equivalent to an order of magnitude increase in sound intensity (for example from 1,000 to 10,000 μPa in pressure).

Importantly, this reference value is different for sounds measured in the air and underwater due to the significant difference in media; roughly, an intensity of (x) dB in the water will be equivalent to an intensity of (x – 26) dB in the air. Given sound intensities stated formally include their standard reference pressures (which also take into account the differences in media), specifically,

pressure_reference in water $= 1\mu Pa$
pressure reference in air $= 20\mu Pa$.

All noise levels given in this document are for underwater sound, and thus are in reference to $1\mu Pa$. The pressure reference is omitted throughout for conciseness.

To help understand the meaning of intensity measurements, sound of Σ90 dB re 20μPa in air, or Σ116 dB re 1μPa in seawater, causes permanent damage to hearing in the human ear. Intensities between 120dB and 130dB re 20μPa in air represent the threshold of causing pain in human listeners.

APPENDIX B

MASKING [Excerpted from NRC (2003); works cited below are not included in bibliography]

One of the most pervasive and significant effects of a general increase in background noise on most vertebrates, including marine mammals, may be the reduction in an animal's ability to detect relevant sounds in the presence of other sounds—a phenomenon known as masking. Masking, which might be thought of as acoustic interference, occurs when both the signal and masking noise have similar frequencies and either overlap or occur very close to each other in time. Noise is only effective in masking a signal if it is within a certain "critical band" (CB) around the signal's frequency. Thus, the extent of an animal's CB at a signal's frequency, and the amount of noise energy within this critical frequency band, is fundamentally important for assessing whether or not masking is likely to occur.

Marine mammals evolved in an environment containing a wide variety of naturally occurring sounds, and thus they show a variety of strategies to reduce masking. Vocal signals may be designed to be robust to masking effects. Signals can be more easily detected in noise if they are simple, stereotyped, and occur in a distinctive pattern. Signals may also show a high level of redundancy; they may be repeated many times to increase the probability that at least some will be detected. However, these characteristics all minimize the amount of information that a signal can convey. Animals can adapt their behaviors to minimize masking, and it is reasonable to interpret such behavioral changes as an indication that masking has occurred. For example, the vocal output of a beluga whale changed when it was moved to a location with higher levels of continuous background noise (Au et al. 1985). In the noisier environment, the animal increased both the average level and frequency of its vocalizations, as though it were trying to compensate for and avoid the masking effects of, the increased, predominantly low-frequency, background noise levels. Penner et al. (1986) conducted trials in which a beluga whale was required to echolocate on an object placed in front of a source of noise. The animal reduced masking by reflecting its sonar signals off the water surface to ensonify to the object. The strongest echoes from the object returned along a path that was different from that of the noise. This animal's ready application of such complex behavior suggests the existence of many sophisticated strategies to reduce masking effects.

Beluga whales increased call repetition and shifted to higher peak frequencies in response to boat traffic (Lesage et al. 1999). Gray whales increased the amplitude of their vocalizations, changed the timing of vocalizations, and used more frequency-modulated signals in noisy environments (Dahlheim 1987). Humpback whales exposed to LFA sonar increased the duration of their songs by 29 percent (Miller et al. 2000). The physiological costs of ameliorating masking effects have not been reported. Although these examples all appear to show animals adapting their vocal behavior to reduce the impact of masking, this does not imply that there were no costs resulting from increased levels of noise. Masking may have been reduced but not eliminated. Costs of the changed behavior, such as increased *energetic expenditure on higher-intensity vocalizations and use of vocalizations at suboptimal frequencies cannot be estimated yet.*